REMARKS

The claims have been amended to more broadly and clearly state the claimed subject matter.

Claims 1 to 23 are rejected under the judicially created doctrine of obviousness-type double patenting as being unpatentable over claims 1 to 4 of U.S. Patent No. 6,397,924, in view of JP 55-165260. Claims 1, and 5-23 are rejected under 35 U.S.C. § 103(a) as being unpatentable over EP 903,190 and further in view of JP 59215257. Claims 2-4 rejected under 35 U.S.C. § 103(a) as being unpatentable over EP 903,190, in view of JP 59215257, and in view of JP 55-165260.

Applicants respectfully traverse these rejections and respectfully request allowance of claims 1-23, presently pending, in view of the following remarks:

Double Patenting Rejection of Claims 1-23: US '924 does not disclose or suggest the claimed subject matter of claims 1-23 or alone or in combination with JP '260. US '924 discloses a twin roll caster to be built with a modular construction in which the casting rolls are installed on a moveable module readily moveable into and out of the machine. The roll cassettes 13 are constructed so that the casting rolls 16 can be set up and the nip between them pre-set at the by-pass position before the cassette is installed in position in the caster. Col. 5, ll. 59-62. Roll cassette frame 102 carries to adjustable spacers 107 in the form of a worm or screw drive jack disposed beneath the rolls 16 about a central vertical plane between the rolls 16 and located between the two pairs of roll supports 104 so as to serve as stops limiting inward movement of the two roll supports thereby to define the pre-set nip position, i.e., the minimum width of the nip between the rolls. Col. 6, ll. 35-42. The roll biasing units 51 act continuously to bias the roll supports 104 inwardly toward the central stops to permit outward springing movement of the rolls against the pre-set biasing forces. Col. 6, ll. 42-45. The spacing between the rolls at the nip during casting can, therefore, be accurately pre-set by the centralized stops and preloading the roll biasing forces biasing the rolls inwardly against the stops. Col. 7, ll. 9-11.

Accordingly, the width of the nips and in turn the thickness of the cast sheet is pre-set by the centralized stops in US '924. The Office Action asserts that US '924 discloses "setting the initial gap between the rolls at the nip which is less than the thickness of the strip to be cast, and gradually increasing the roll gap to accommodate the width of the initial cast strip". *Id.* page 2. Applicants respectfully disagree. To the contrary, US '924 explains that the casting rolls are preloaded with appropriate biasing forces as soon as the cassette has

installed "and it is not necessary as in previous casters to wait for metal to flow through the rolls to develop reactive forces resisting roll separation". Col. 7, ll. 13-16. US '924 therefore teaches that the width of the cast strip is determined by the preset nip spacing determined by adjustment of the centralized stops. The presently claimed subject matter teaches directly to the contrary that the initial gap set between the casting rolls in less than the thickness of the strip to be initially cast, and that the casting rolls are laterally moved from a pre-set initial gap to the desired thickness of the strip by moving a casting roll laterally against the continuous bias to increase the gap between the rolls to the thickness of the cast strip.

JP '260 (translation attached hereto) is also further evidence of **non-**obviousness of the presently claimed subject matter. To the contrary, JP '260 explains that as part of its disclosure "a pair of rolls... have been previously so set as to leave a gap g' of the same dimensions as the desired gauge of the product, and wherein the molten metal is cooled by the rolls 1 an 1 and is rolled to directly manufacture the strip 5". JP '260 Translation at p. 4, ll. 4-7 (Translation attached hereto). Again, there is no disclosure or suggestion that the pre-set gap between the casting rolls can or should be later increased to greater than the gap set between the casting rolls and causing one of the casting rolls to move laterally away from the other casting roll against the continuous bias to increase the gap between the rolls to the thickness of the initially cast strip.

<u>Obviousness rejection of claims 1, 5-23</u>: EP 903, 190 does not disclose or suggest the presently claimed subject matter of claims 1 and 5-23 either alone or considered together with JP '257. EP '190 discloses a twin roll caster that permits accurate setting to a predefined appropriate width for the nip that is to be the thickness of the cast strip, generally on the order of a few millimeters. A roll cassette frame 102 carries two adjustable spacers 107 disclosed beneath the rolls about a center vertical plane between the rolls and located between the two pairs of roll supports 104, so as to serve as stops limiting inward movement of the two roll supports thereby to define the minimum width of the nip between the rolls. Col. 5, ll. 52-58. Each centralized spacer 107 is in the form of a worm or screw driven jack having a body 108 fixed relative to the center vertical plane of the caster in two ends 109 which can be moved on actuation of the jack equally in opposite directions to permit expansion and contraction of the jack to adjust the width of the nip while maintaining equal distant spacing of the rolls from the center vertical plane of the caster. Col. 6, ll. 5-13. "Since the biasing unit bracket acts to bias the roll support 104 inwardly against the stop it can be adjusted to preload the roll support with a required spring biasing force before metal

actually passes through the casting rolls and that biasing force will be maintained during a subsequent casting operation". Col. 7, ll. 15-20.

Accordingly, there is no disclosure or suggestion in EP '190 of setting the initial gap between the casting rolls at the nip less than the thickness of the strip to be initially cast and than casting to a thickness greater than the gap set between the casting rolls causing one of the casting rolls to move laterally away from the other casting rolls against the continuous bias to increase the gap between the rolls to the thickness of the cast strip.

JP 59215257 (translation attached hereto) is evidence of **non**-obviousness of claims 1, 5-23, considered alone or in combination with EP '190. JP '257 teaches that where the gap between the rolls is set less than the desired thickness of the cast strip that the initial velocity of the counter-rotating casting rolls must be adjusted to correspond to the roll gap, so that cast strip of the thickness of the gap set is initially produced. JP '257 teaches that once the cast strip is initially produced that the roll speed is gradually adjusted in coordination with change of the roll speed to produce strip of increased thickness. As Figure 2 of JP '257 shows without the coordinated gradual adjustment of roll gap and roll velocity strip cannot be produced.

Specifically, JP '257 teaches:

> **After casting of metal strip with a strip gauge t_1 = 2mm and a roll circumferential velocity V_1 = 20m/min has commenced, the roll velocity V is next gradually increased and the roll gap G is gradually widened, but in this case, the roll circumferential velocity and the strip gauge (or alternatively, the roll gap) must be adjusted so that the point of intersection of the roll circumferential velocity V and the strip gauge *t* (or alternatively, the roll gap G) in Figure 2 at any point in time is within the zone Z within which metal strip can be cast.** Thus the roll circumferential velocity V_2 if the desired strip gauge t_2 is 4mm is approximately 10m/min, and the operation point is point B in Figure 2.
>
> In this manner, it is possible smoothly to continuously cast thick gauge metal strip.

JP '257 Translation at 4 (emphasis added).

Thus, JP '257 teaches away from the present invention which provides for cast strip of the desired casting thickness without going through the gradual increase in thickness after strip has been initially cast.

Obviousness rejection of claims 2-4: Claims 2-4 are rejected based on EP '190, in view of JP '257 and further in view of JP 55-165260. This rejection fails in its premise in that EP '190 and JP '257 do not disclose the claimed subject matter of claims 1, and 5-23 as described above.

JP '260 does not fill the deficiencies in the disclosure of EP '190 and JP '257. JP '260 does not even deal with the problem of start up of a twin roll caster. Rather, JP '260 teaches that the strip will be cast throughout the casting run at the gap g' set for the thickness of the strip to be cast. Specifically, JP '257 states that gap g' has "been previously so set as to leave gap g' of the same dimensions as the desired gauge of the product". Translation at 4, ll. 5-6.

Accordingly, applicant respectfully request that the pending claims 1-23, as amended, be reconsidered, and that the claims be allowed and the application passed to issue. If the Examiner has any further questions or concerns regarding the patentability of the claims after review of this amendment and further review of the prior art cited, applicant respectfully requests that the Examiner call their attorney, Arland T. Stein, Esq. (317-231-7390) to resolve any remaining questions.

Respectfully,

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B 22 D 11/06 7109-4E

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(54) Title of Invention: Method of Casting for Twin Roll Type Continuous Casting Machine

(21) Patent Application Number: 58-88896

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SPECIFICATIONS

1. Title of the Invention

Method of Casting for Twin Roll Type Continuous Casting Machine

2. Claims

1) A method of casting for a twin roll type continuous casting machine, such method characterized in that, in a twin roll type continuous casting machine in which a plurality of rolls is disposed horizontally, molten steel is supplied over such rolls and metal strip is continuously extracted from the roll gap, the roll gap is narrowed when the melt is first supplied and casting is commenced from a metal strip having a thinner gauge than the desired gauge, whereupon the roll gap is widened and the circumferential velocity of the rolls is made lower than that when strip of a thinner gauge is cast, and strip with a thicker gauge is cast

3. Detailed Description of the Invention

The present invention relates to a method of casting for a twin roll type continuous casting machine which facilitates startup when metal strip with a thick gauge is continuously cast.

Many different methods of continuous casting of metal strip by means of twin roll type continuous casting machines have been proposed in recent years, and in continuous casting machines rolls **1** and **2** are disposed parallel to each other as shown in Figure 1. Such rolls **1** and **2** are so constituted as to be capable off being adjusted by means of screw shafts so that the roll gap **G** is fitted to the strip gauge and are so constituted as to rotate in the directions of the arrows by a drive mechanism. Barrel seals are disposed above the rolls **1** and **2** and side seals are disposed at the two ends of the rolls **1** and **2**, and the molten steel is caused to pool in the space enclosed by the barrel seals and the side seals above the rolls **1** and **2**.

When metal strip is continuously cast by means of such twin roll type continuous casting machines, the roll gap **G** is adjusted to the desired dimensions and the rolls **1** and **2** are caused to rotate in the directions of the arrows, the molten steel **4** is supplied from the ladle **3** into the space enclosed by the barrel seals and the side seals above the rolls **1** and **2**, and the solidified layers that cool and are formed on the surfaces of the rolls **1** and **2** are withdrawn, whereby metal strip is continuously cast.

Thus, when the gauge of the metal strip that is cast is thick, the roll gap **G** is widened and hence the molten steel that is supplied from the ladle **3** immediately after the commencement of pouring is not able to pool in the space enclosed by the barrel seals and the side seals above the rolls **1** and **2** but flies through the roll gap forming splashes **5**. For this reason, the yield and productivity of this method are poor.

Hence consideration has been given to a method of stopping the rolls **1** and **2** when the pouring of the molten metal commences, inserting a dummy bar formed of asbestos or an insulating material into the roll gap, causing the rolls **1** and **2** to rotate after the molten steel has pooled, then removing the dummy bar and commencing casting, but not permitting the rolls to rotate when molten steel is supplied and then causing the rolls to rotate after the molten steel has been supplied causes the problem that the molten steel between the rolls **1** and **2** cools and solidifies, forming a V block.

Moreover, when the rolls **1** and **2** are caused to rotate and the dummy bar is inserted into the roll gap, and the dummy bar is extracted from between the rolls **1** and **2** a short period of time after insertion because the dummy bar cannot be too long, the molten steel is unable to pool over the rolls immediately after the commencement of the supply of molten steel.

The present invention takes account of the difficulties of employing a dummy bar when thick gauge strip is continuously cast in a twin toll type continuous casting machine, and the present invention has been created with the objective of enabling the commencement of casting of thick gauge metal strip, without the necessity for the use of a dummy bar when the supply of molten steel commences, and without the formation of splash immediately after the supply of molten steel commences.

In the method envisaged by the present invention, the roll gap is set sufficiently narrowly as to prevent the formation of splash when the supply of molten steel commences, and the roll gap is altered to the roll gap that corresponds to the desired strip gauge when the withdrawal of metal strip commences. Consequently, it is readily possible to commence the casting of metal strip of a thick gauge immediately after the supply of molten steel commences without the formation of splash, and without the necessity to employ a dummy bar.

A practical embodiment of the present invention is described below.

First, the principle of the present invention is explained by reference to the graph in Figure 2. There is a zone X in the strip gauge *t* that is continuously cast or alternatively between the roll gap **G** and the roll circumferential velocity V in which, when the strip gauge *t* or alternatively the roll gap **G** equals or exceeds a certain value, the molten steel splashes and leaks downwards, and there is a zone Y in the strip gauge *t* that is continuously cast or alternatively between the roll gap **G** and the roll circumferential velocity V in which, when the strip gauge *t* or alternatively the roll gap **G** is equal to or below a certain value and the roll circumferential velocity V is below a certain value, the molten steel solidifies and forms a V block, and there is a zone Z (enclosed by the curves (a) and (b)) between the zones X and Y in which the metal strip can be cast. The curve (c) is produced when the mid-point positions between curves (a) and (b) are plotted, but the curve (c) can generally be represented by $t = K \cdot V^{-0.5}$. Here, K is a constant which varies according to steel type and the temperature conditions, but is generally within the zone of from 8 to 10 in the case of 500 mm ϕ twin rolls. Consequently, the values of each point on the curves (a) and (b) are approximately ±10% in relation to the values of curve (c), and the ideal state of the zone of approximately ±10% is the zone Z in which metal strip can be cast. Moreover, there is an upper limit C for the strip gauge *t* and the roll gap **G** at which a dummy bar is not required, within the zone Z within which metal strip can be cast. Consequently, if for example point A is the operation point below the upper limit C within the zone Z at which the operation of pouring the molten steel is commenced, and point B is the operation point above the upper limit C within the zone Z at which it is possible to operate in order to obtain the desired strip gauge, it is still possible to cast metal strip of a thick gauge without the necessity to employ a dummy bar and without the development of splash from the molten steel, provided that the strip gauge *t* or alternatively the roll gap **G** are not varied so as to fall outside the zone Z, even if the operating conditions are varied from point A to point B.

Next, a specific embodiment of the invention is described. The diameter of the rolls **1** and **2** in Figure 1 is 500 mm φ, and when mild steel (S10C) with a strip gauge of 4 mm is continuously cast by means of this continuous casting machine, the roll circumferential velocity V_1 at the commencement of casting is 20 m/min, molten steel is pooled above the rolls **1** and **2** without the use of a dummy bar, and metal strip with a strip gauge t_1 of approximately 2 mm is cast first. The operation point in this case is point A in Figure 2. Consequently, there is no leakage of molten steel from between the rolls **1** and **2** and no splash develops when operations commence.

After casting of metal strip with a strip gauge $t_1 = 2$ mm and a roll circumferential velocity $V_1 = 20$ m/min has commenced, the roll velocity V is next gradually increased and the roll gap **G** is gradually widened, but in this case, the roll circumferential velocity and the strip gauge (or alternatively, the roll gap) must be adjusted so that the point of intersection of the roll circumferential velocity V and the strip gauge t (or alternatively, the roll gap **G**) in Figure 2 at any point in time is within the zone Z within which metal strip can be cast. Thus the roll circumferential velocity V_2 if the desired strip gauge t_2 is 4 mm is approximately 10 m/min, and the operation point is point B in Figure 2.

In this manner, it is possible smoothly to continuously cast thick gauge metal strip.

The generality of the present invention is not restricted by the preceding practical embodiment thereof, and naturally, various modifications may be made thereto, provided only that they do not deviate from the spirit of the invention.

The method of casting for a twin roll type continuous casting machine envisaged by the present invention does not require the use of a dummy bar and does not generate splash, but permits the casting of thick gauge metal strip, while facilitating startup and permitting casting to be operated with good efficiency, and while improving yield because there is no loss due to splash of molten metal.

4. Simplified description of the drawings

Figure 1 is an explanatory drawing of the splash that is generated when the casting of thick gauge metal strip is commenced directly, and Figure 2 is a graph showing the relationship between the roll circumferential velocity and the castable strip gauge or roll gap.

In the drawings, **1** and **2** are rolls, **3** is the ladle, and **4** is the molten steel.

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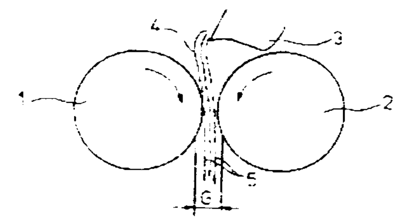

Figure 1

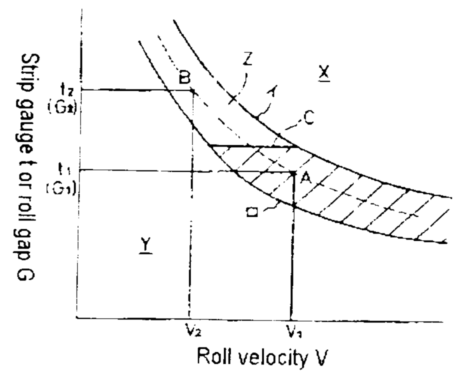

Figure 2

55-165260

-1- (WPAT)	
ACCESSION NUMBER	89-204572/28
SECONDARY ACCESSION	C89-091085
XRPX	N89-156125
TITLE	Hoop prodn. from molten metal - by rolling molten metal between rolls with circumferential grooves, for mfg. iron-silicon-aluminium alloy hoops (J5 23.12.80)
DERWENT CLASSES	M22 P53
PATENT ASSIGNEE	(FURU) FURUKAWA ELECTRIC CO
NUMBER OF PATENTS	2
PATENT FAMILY	J89030582-B 89.06.21 (8928) (JP)
	J55165260-A 80.12.23 (8928) (JP)
PRIORITY	79.06.08 79JP-071978
APPLICATION DETAILS	79.06.08 79JP-071978
INT'L. PATENT CLASS.	B22D-011/06
ABSTRACT	(J89030582) Producing hoop from molten metal comprises rolling molten metal between pair of rolls with circumferential grooves of 0.003-0.2 mm. deep and wider than width of hoop, grooves with circular or elliptic cross sectional shape. Used for making Fe-Si-Al alloy hoops. (J55165260-A) (4pp Dwg.No.0/8)

ACCESSION NUMBER	80-165260
TITLE	DIRECT PRODUCTION OF SHEET FROM MOLTEN METAL
PATENT APPLICANT	(2000529) FURUKAWA ELECTRIC CO LTD:THE
INVENTORS	KIKUCHI, SUKEYUKI; FUJITA, NOBORU; UENO, OSAMI; MOGI, HISASHI
PATENT NUMBER	80.12.23 J55165260, JP 55-165260
APPLICATION DETAILS	79.06.08 79JP-071978, 54-71978
SOURCE	81.03.14 SECT. M, SECTION NO. 59; VOL. 5, NO. 39, PG. 115.
INT'L PATENT CLASS	B22D-011/06
JAPIO CLASS	12.4 (METALS--Casting)
ABSTRACT	PURPOSE: To prevent the occurrence of cracking and obtain the product of the thickness relatively even in the width direction by providing the concave circumferential grooves of a width wider than the desired sheet product on the surfaces of the rolls which directly roll molten metal. CONSTITUTION: Concave circumferential grooves 2, 2 of a width wider than the desired product width, for xample, arc form, are provided on the surfaces of a pair of rolls 1, 1 which roll the molten metal of brittle material such as Fe-Si-Al- base alloy directly to a sheet. While these rolls 1, 1 are being revolved in the arrow direction, molten metal is passed and cooled in the spacing between the rolls, whereby the intended sheet product is obtained. These provide effect such as the decrease in local screw-down owing to the expansion of the rolls, and the increase in thermal capacity of the central part in the width direction where cracking tends to occur at the passing of molten metal, and this helps prevent the occurrence of cracking even with a much thinner sheet product.

19 JAPAN PATENT AGENCY (JP)

11 PUBLICATION OF PATENT APPLICATION

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45 Publication date: 21st June 1989

Number of Claims: 1 (Total 4 pages)

54 Title of Invention: Method of Manufacturing Strip Directly from Molten Metal

Examination 8945 of 1987

21 Patent Application: 71978 of 1979

22 Application date: 8th June 1979

65 Laid Open No.: 165260 of 1980

43 23rd December 1980

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56 Reference: Japanese Patent Application No. 73449 of 1980 (JP, A)

57 Claims

A method of manufacturing strip directly from molten metal characterized by a method of manufacturing strip in which molten metal is directly rolled between a pair of rolls, wherein the surface of the said pair of rolls possesses a width greater than the desired width of the strip, and wherein annular grooves of a maximum depth of from 0.03 mm to 0.2 mm are provided in a recessed portion possessing a circular or elliptically shaped cross section of the surface which includes the roll shaft, and wherein molten metal is caused to flow from a nozzle whose width is more narrow than the width of the annular grooves between the annular grooves of the recessed portion while the said rolls are revolving, such that the molten metal passes between the annular grooves and is cooled.

Detailed Description of the Invention

Area of application within industry

The present invention relates to a method for the manufacture of strip by directly rolling molten metal between a pair of rolls. The strip formed in this manner is not more than 1 mm thick and is of not more than approximately 100 mm wide.

Prior art

Hitherto, brittle materials such as Fe-Si-Al alloys have been difficult to work, and hence there have been few examples in the prior art of the direct rolling and manufacture of strip from such

materials, although there have been examples of the employment of cast iron flat rolls for the direct rolling of strip.

Figure 6 illustrates an example of a method of direct rolling, wherein molten metal **7** is poured from a nozzle **8** to between a pair of rolls **1** and **1** which are revolving in the directions indicated by the arrows and which have been previously so set as to leave a gap **g'** of the same dimensions as the desired gauge of the product, and wherein the molten metal is cooled by the rolls **1** and **1** and is rolled to directly manufacture the strip **5**. The shape of the orifice of the nozzle **8** that is employed may be appropriately selected from a circular, elliptical or rectangular shape of a width corresponding to the width of the strip **5** or alternatively a plurality of such shaped orifices, and generally such casting is performed under conditions of numbers of roll revolutions and so forth as to ensure that the mass of strip **5** that is obtained per unit time is approximately equal to the mass of molten metal **7** that flow from such nozzle per unit time.

Problems addressed by the present invention

When direct rolling is performed by means of such flat rolls, a temperature profile develops across the width of such roll, and localized thermal expansion with the centre of the flat roll exhibiting the greatest temperatures causes the product to exhibit shapes in which there is greater thickness at the two edges **a** than at the centre **b** as shown in the cross section illustrated in Figure 7, such that it is difficult to obtain a product exhibiting a uniform gauge across the width of the strip.

Moreover, when a product having the shape shown in Figure 7 is produced, rolling marks become more clearly formed with greater proximity to the centre of the strip as the rolls pass over the strip, such that many cracks develop in the vicinity of the centre of the strip, and the product is often unsuitable for use.

Thus, a method which would prevent the development of cracks and provide a relatively uniform gauge across the width of the strip when strip is manufactured by the direct rolling method from stock which is difficult to work such as Fe-Si-Al alloys has been eagerly sought.

Means by which such problems are resolved

The inventors of the present invention have taken account of such desires, and as a result of experimentation and research have perfected the present invention by discovering that, when the variations in thickness across the width of the strip due to the thermal expansion of the rolls are relatively great, such thermal expansion may be regarded as portions of an ellipse centred on 3″and 3″ as shown in Figure 8 (a), and when such variations in thermal expansion are relatively small, such thermal expansion may be regarded approximately as portion of a circle centred on 3‴ as shown in Figure 8. Thus, the present invention is able to achieve the simultaneous prevention of the development of cracks and the manufacture of strip which exhibits uniform gauge across the width of such strip by previously providing on the surfaces of the pair of rolls recessed annular grooves over portion of an ellipse or portion of a circle corresponding to the desired width of the strip.

Action

The present invention is particularly effective in enabling the manufacture by rolling of strip through the use of direct rolls from molten metal consisting of brittle materials such as Fe-Al-Si alloys.

Thus, materials such as Fe-Si-Al alloys have poor workability, and hence hitherto cast slab has been prepared from such materials in order to manufacture strip having a thickness of approximately 0.3 mm, and such cast slab was subjected to time-consuming methods of working such as grinding and cutting and so forth, but the direct rolling method envisaged by the present invention is most beneficial to industry in that the present invention permits the efficient provision of strip of Fe-Si-Al alloys, such strip having greater gauge stability than that obtainable with the flat roll method of the prior art, and without the development of cracks in the strip.

The present invention is described by means of the diagrams, wherein Figure illustrates an embodiment of the present invention wherein annular grooves 2 and 2 are provided in the surfaces

of the pair of rolls **1** and **1**, such annular grooves taking the form of for example recessed ellipses which possess widths greater than the desired width of the strip to be manufactured, and wherein, while the rolls **1** and **1** are revolving in the directions indicated by the arrows, molten metal passes through the gap between the said rolls **1** and **1** and is cooled thereby, whereby the intended strip is obtained.

When the aforementioned rolls **1** and **1** are employed, the effects of, first, the diminished localized reduction due to the expansion of the rolls, and secondly, the increase in the heat at the centre of the width of the strip, at which cracking readily develops when the molten metal passes through the gap between the rolls, serve to prevent the development of cracking, even in yet thinner strip.

The width of the strip may be selected according to the shape of the orifice of the nozzle, the area of the cross section of the nozzle, the roll diameter, and the roll rotational velocity and so forth, but the width of the aforementioned grooves **2** that are disposed upon the surfaces of the rolls must be greater than the width of the intended strip, and the shape of the recessed annular grooves **2** may be a portion of a circle **4** centred on 3 as shown in Figure 2 (a), or a portion of an ellipse **4'** centred on **3'** and **3'** as shown in Figure 2 (b).

Moreover, the depths of the aforementioned recessed annular grooves **2** vary according to the temperature of the molten metal and the gauge of the strip, but are preferably between 0.03 mm and 0.2 mm, and more preferably between 0.05 mm and 0.1 mm.

If the depths are not more than 0.03 mm, the two effects described in the foregoing are reduced and approach those obtained with strip from flat rolls (Figure 7), and readily develop cracking, while on the other hand, if the depths are not less than 0.2 mm, the curvature of the strip increases laterally as shown in Figure 3, and the gauge of the strip is variable.

Furthermore, the widths of the recessed annular grooves **2** as described in the foregoing are greater than the width of the strip **5** because if the widths of the annular grooves **2** are smaller than the width of the strip **5**, that portion of the strip that does not fall into the annular grooves

exhibits the same effects as those achieved with flat rolls, and as shown in Figure 4, a lustrous surface **6** with cracks at the two edges of the strip **5** is obtained.

The outer circumference and number of revolutions (circumferential velocity) of the rolls **1** and **1** and so forth may be set appropriately, but generally, thin strip is easier to manufacture with smaller roll diameters. However, this is also affected by the number of revolutions of the rolls, and hence the number of revolutions of the rolls must be increased as the outer diameters of the rolls are reduced.

Practical embodiments

Practical Embodiment 1

A pair of rolls **1** and **1** (roll diameters 200 mm ϕ, total width W = 43 mm) formed of S45C and which possess recessed annular grooves **2** which form near arcs of depth d = 0.1 mm and width w = 20 mm as shown in Figure 5 are set in such a manner as to leave a gap between of the rolls at the two ends of the rolls of g = 0.3 mm and a maximum gap of 0.5 mm, and molten metal having a composition of Si 9.6 wt%, Al 6.2 wt% and with the balance consisting of Fe is permitted to fall naturally from a rectangular nozzle **8** having a width of 10 mm and a depth of 0.8 mm between the rolls **1** and **1** while such rolls are revolving at a constant velocity of 100 rpm, and such molten metal is rolled directly.

As a result, directly rolled strip having a lateral gauge of 0.4 mm and a width of 11.5 mm is obtained; no micro cracks are observed in such strip.

Practical Embodiment 2

Hollow rolls (roll diameters 200 mm ϕ, total width W = 43 mm) formed of S45C and which possess recessed annular grooves **2** which form near arcs of depth d = 0.05 mm and width w = 15 mm as shown in Figure 5 are set in such a manner as to leave a gap between of the rolls at the two ends of the rolls of g = 0.3 mm and a maximum gap of 0.5 mm, and direct rolling is performed under the same conditions and by the same method as for Practical Embodiment 1.

As a result, strip **5** having a width of 12 mm and a gauge of 0.4 mm is obtained. In this case, similarly to the results achieved with Practical Embodiment 1, no micro cracks are observed, and the strip is of sufficient quality for use as finished product.

For purposes of comparison, a pair of hollow flat rolls formed of S45C and having total widths W of 43 mm and outer diameters of 200 mm ϕ is set to provide a gap of 0.4 mm, and direct rolling is performed under the same conditions and by the same method.

As a result, the product obtained has a width of 13 mm and a gauge at the centre of 0.3 mm and at the two edges of 0.36 mm.

Moreover, with the exception of the very small areas at the two edges, virtually the entire surface exhibits vertical and horizontal micro cracks of varying sizes. The depths of such micro cracks are from approximately 50 microns to 100 microns, and hence such strip is of very little use as a finished product.

Effects of the present invention

By means of the present invention as described in the foregoing, a pair of rolls which are provided with recessed annular grooves greater in width than the desired strip was employed, and a molten metal consisting of a brittle material such as Fe-Si-Al alloy was directly rolled, whereby strip which was free of cracking and which exhibited uniform gauge across the width of the strip, such being basic preconditions for strip, was obtained, which permitted the manufacture of industrially and economically advantageous products from strip which was formed of brittle materials such as Fe-Si-Al alloys which were hitherto relatively difficult to work.

Moreover, because the present invention allows strip to be obtained directly from molten metal, the process for the manufacture of strip from brittle materials such Fe-Si-Al alloy and so forth, which hitherto required many complex stages, is greatly simplified, and thus the present invention provides significant industrial benefits.

Simplified Description of the Diagrams

Figure 1 is an explanatory diagram of a pair of rolls which possess recessed annular grooves and which is employed by the present invention; Figure 2 (a) and (b) are diagrams of examples of the implementation of such recessed annular grooves; Figure 3 is a cross-sectional diagram of strip when the depths of the recessed annular grooves envisaged by the present invention are excessive; Figure 4 is a partial front elevation of the condition of the strip when the width of the annular grooves in Figure 1 is less than the width of the strip; Figure 5 is an explanatory diagram of the rolls with annular grooves that are employed in a practical embodiment of the present invention; Figure 6 is an explanatory diagram which shows the status when molten metal is directly rolled by means of a pair of rolls, and Figure 7 and Figure 8 (a) and (b) are cross-sectional diagrams of the strip that is obtained by the direct rolling method of the prior art

1 ... Roll with annular grove; **2** ... Recessed annular grove; **3, 3', 3", 3'''** ... Centres of circles or ellipses that form the shapes of the annular grooves; **4, 4'** ... Same - circles or ellipses; **5** ... Strip; **6** ... Lustrous surface; **7** ... Pool of molten metal; **8** ... Nozzle; **a** ... Two edges of strip; **b** ... Centre of strip; **d** ... Maximum depth of annular groove; **w** ... Width of annular groove; **W** ... Total length of roll **1**; **g** ... Gap between two edges of the rolls **1** and **1**

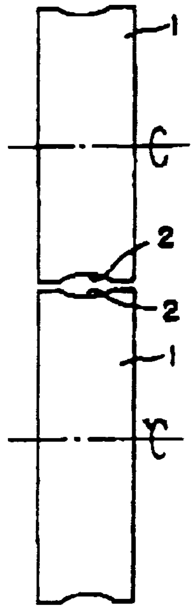

Figure 1

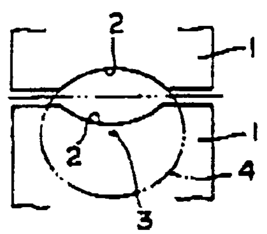

Figure 2 (a)

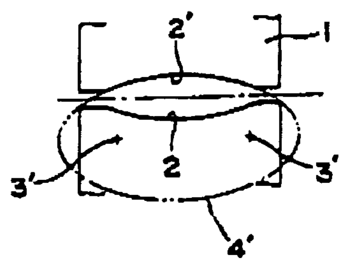

Figure 2 (b)

Figure 3

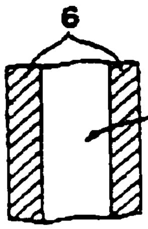

Figure 4

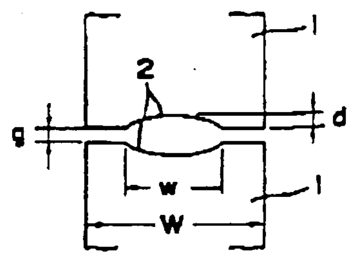

Figure 5

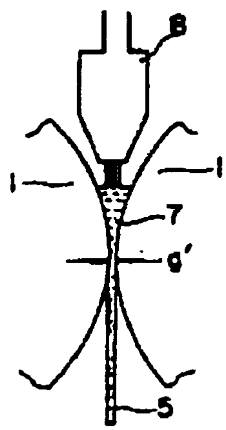

Figure 6

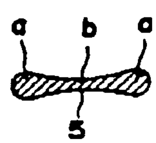

Figure 7

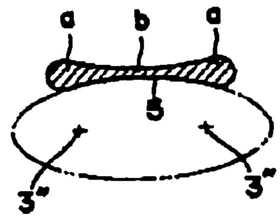

Figure 8 (a)

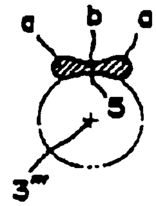

Figure 8 (b)